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SOME SPECIAL ASPECTS OF THE COMBINED POWER AND SEA-WATER CONVERSION PLANT AT ARUBA, N.W.I., WITH A VIEW TO THE PARTICULAR MERITS OF COMBINED PROJECTS FOR DEVELOPMENT PROGRAMS IN GENERAL

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A. Introduction

At Balashi, Aruba, in the Netherlands West Indies since a few years a combined power and sea-water conversion plant is turning out distilled water for the governmental water supply as well as for the local Lago Oil Refinery together with a substantial amount of electric power, generated by the steam that is used ultimately in the water distillation plant. The actual net capacity of the whole complex amounts to 2.7 million g/day of distilled water plus 10.000 marketable kilowatts.

With an annual precipitation below 33 cm the isle of Aruba constitutes a typical example of an isolated extremely arid country, comprising 170 sq. kilometres of land, entirely deprived of any natural water supply. Consequently its 54.000 inhabitants have to rely completely on converted sea-water for all their domestic as well as industrial needs.

The new combined power and fresh water plant to be described briefly in this paper has resulted in a considerable cost saving as compared to the cost that would have been involved in producing the same amounts of power and of fresh water in two separate plants. For that reason this plant has been chosen by the authors of this paper to present the case of reducing total production cost by appropriate planning and combined installation of such important means of development as water and power supply.

In addition the possibilities will be pointed out of further combinations including the latest tool in saline water conversion, electrodialysis. Though such combinations have not yet been applied in actual practice, a substantial reduction in cost is to be expected particularly in areas where complete new developments are to be laid out.

B. Description of the Balashi Plant

200.000 lbs/h of steam are raised (generated) in one of two Babcock & Wilcox boilers, the second one serving merely as standby. At 875 lbs/sq. inch and 820°F this steam enters into two generators of rated capacity

10.000 kVA each. At a power factor 0.75 the corresponding rated energy capacity will amount to 15.000 kilowatts. Boiler make-up is distilled water obtained from the evaporators.

The steam leaving the turbines at an exhaust pressure of 1.4 kg/cm2 is used for evaporation of the sea-water to be distilled. The actual distillation plant comprises five sextupel effect evaporation units, having a capacity of 540.000 g/day of distilled water each.

The total plant was designed for a steam economy of about 5 lbs of distilled water per pound of steam (134 k.cal/kg of water). The above steam economy, together with the values quoted for throttle and exhaust pressures and temperatures will result in the required ratio between energy and water production. This ratio should be based on reasonable expectations as to the future needs of energy and water.

Each evaporating unit comprises seven shells, together constituting the six effects, the fifth effect having been carried out in the form of two shells. Actually in the fifth effect the sea-water temperature reaches a value of 65°C above which precautions are to be taken against scale formation. This is done by means of the so-called "scale master", an electrolytic device providing for the addition of an appropriate amount of $FeCl_3$ produced on the spot at this very fifth effect by electrolysis consuming an iron anode.

The evaporators are of the submerged coil type.

The feed is sea-water, 29°C, filtered only through a wide mesh metal gauze. The waste brine is leaving the plant at 75.000 p.p.m. at 130°F. The distilled water, pH 5.5 and containing less than 5 p.p.m., is given a final polishing treatment before delivery.
For about half the total quantity, which is delivered to the Lago Oil Refinery, this final treatment is restricted to the addition of a small amount of caustic soda and of sodium hexa-metaphosphate. The remainder to be delivered for domestic use is led across a coral lime stone bed improving the taste, the pH is raised to 8.3 by means of sodium carbonate after which a slight fluoridization is applied. The usual chlorination was not considered necessary since the distillate has been exposed to rather high temperatures.

The maximum load of the evaporator (425 tons/h) is reached at a steam rate of 87 tons/h (i.e. just below the full steam capacity of the boiler: 200.000 lbs/h or 90 tons/h).

The steam rate at full load of the back-pressure turbines is reported to amount to 7.11 kg/kWh of steam (1).
Hence the maximum energy production will amount to about 12.500 kilowatts. The energy requirements of the auxiliary equipment are 1.500 kW for the 5 evaporators and 1.000 kW (8% of the total production) for the power station. This leaves a net production of 10.000 kilowatts.

The ratio between the potential water production capacity and the potential energy production capacity has been chosen considerably higher than the ratio between present-day water consumption. In the years to come, the energy consumption is expected to increase more rapidly than the water consumption. In order to adjust the plant to the present ratio part of the high pressure steam is now bypassed and its pressure simply reduced to the value of the exhaust pressure so as to cope with the need of the

evaporators.

The above data have been extracted from the literature mentioned under 1), 2), 3) and 4), to which interested readers are referred for further information.

C. Advantages of the Balashi plant over a separate power plant and water distilling plant of the same capacity.

It may be of interest to compare the actual cost and energy consumption etc. of the Balashi plant with the values of the corresponding parameters in the case of two separate plants, one for water supply and one for power supply.

In drawing up an appropriate basis of comparison the following considerations have been taken into account.

In the Balashi plant conventional submerged coil evaporators have been applied, this method of evaporation being the only really foolproof method at the time the plant was designed. Nowadays in many cases flash-type evaporators appears to be preferable. A combined power and water supply plant with multiple flash evaporation is under construction at the isle of Curaçao today (5).
In actual practice sea-water evaporators should not operate at too high temperatures because of the risk of scale formation. Two kinds of scale may occur viz. on the one hand alkaline deposits and on the other hand calcium sulphate deposits. The formation of alkaline deposits can be suppressed at low cost e.g. by means of the "scale master" device applied in the Balashi plant. This does not hold for the calcium sulphate deposits. Without entering into the complicated solubility diagrams and the kinetics of the formation of the various modifications of calcium sulphate, we can state that among other things the negative solubility product of calcium sulphate and the specific power consumption of the evaporator will set limits to the maximum values of the allowable concentration factor and temperature. These values can be exceeded only if either all the calcium ions or all the sulphate ions are removed in advance, a rather expensive procedure. Consequently sea-water evaporators can be operated only with low pressure steam e.g. 1.5 atm.

The cost of steam, however, does hardly depend on the pressure at which the steam is generated. Hence follows the obvious conclusion to generate high pressure steam first for the production of mechanical energy and to use the exhaust steam in a water evaporation plant. The resulting combination of a power plant using back-pressure turbines and evaporators will turn out water and energy more cheaply than a separate water and a separate power plant can do. The marked difference between the two cases will be clear from the data listed in table 1. For the sake of simplicity all these data relate to continuous full load operation.

Table 1

Comparison of characteristic data for a combined power and water supply plant and for separate plants.

	Combined back-pressure turbine and evaporation plant (Balashi, Aruba).	Calculated separate water plant and power station (assuming 30% overall efficiency and power factor 0.75.)
Kilowatts generated	12.500	12.500
Kilowatts used in power section or station	1.000	1.000
Kilowatts used in evaporation plant	1.500	1.500
Marketable kilowatts	10.000	10.000
tons/h of fresh water produced	425	425
Necessary amount of heat (k.cal/h), to be supplied as fuel	80.10^6 (steam generator efficiency assumed at 85%)	116.10^6
steam generators	2 units 90.000 kg/h output each	2 units 90.000 kg/h output each for evaporator plant; 2 units 50 t/h each for power plant.
Turbines and generators	2 back-pressure turbines + generators 7.500 kW (10.000 KVA each)	2 condensing turbines + generators 7.500 kW (10.000 KVA each)
Evaporators	5 sextupel effect evaporator units, 85 t/h each.	5 sextupel effect evaporator units, 85 t/h each.
Total investment cost	$ 12.500.000.—	$ 16.000.000.— (estimated).

Hence it appears that the total cost of a water distillation plant and a separate power station with an output equal to that of the Balashi plant would have required 145% of the investment spent in the Balashi plant. Furthermore the separate plants would take up 128% of the energy consumed by the Balashi plant.

D. Advantages that may be obtained in similar plants by means of other combinations, including electrodialysis.

As has been shown above the Balashi plant constitutes and example of an efficient combination of power generation and water production. For that reason we have chosen this case to demonstrate to what extent even more efficient combinations are possible now that only a few years have elapsed since this plant was designed. To that purpose we shall consider a fairly different lay-out, including some other methods of desalting.

In the Aruba case 145 t/h out of the total amount of 425 t/h of fresh water produced are supplied to the Lago Oil Refinery whereas the balance (i.e. 280 t/h)are used for domestic purposes (local drinking water supply). This means that in fact 145 tons/hour of pure distilled water are needed as against 280 t/h of drinking water that should meet the standard requirement of salt content below the 500 p.p.m. mark.

Hence one might consider to apply distillation combined with back-pressure turbine power generation to the production of these 145 t/h only. Like in the present plant we shall assume a steam economy of 4.88 lbs of distilled water per pound of steam, which means that 30 t/h of steam (i.e. 27.4. 10^6 Kcal/h of fuel in the case of a steam generator efficiency of 85%) are needed for this purpose. Using the same steam rate as in the Balashi plant the corresponding energy figures are estimated to be:

Kilowatts generated	:	4.300
Kilowatts used in power section	:	350
Kilowatts used in evaporator plant	:	500
Marketable kilowatts	:	3.450

In the present Balashi plant 87 t/h of steam are necessary for the production of 425 t/h of water. Starting from the same quantity of steam we find that after spending 30 t/h of steam for the purpose described above a balance of 57 t/h (52. 10^6 Kcal/h at 85% steam generator efficiency) is still available for other purposes. Now let us assume that this quantity of steam is used entirely in an appropriate power station equiped with condensing turbines. At 30% efficiency the yield will amount to 18.600 kilowatts. If 1450 kilowatts are spent in the power station the net output will be: 17.150 kilowatts.

Together with the net output of the back-pressure turbine generators, this means a total output of 20.600 marketable kilowatts.

At Aruba under present-day conditions an amount of 10.000 marketable kilowatts is necessary. This leaves a balance of 10.600 kilowatts available for the production of the 280 t/h of drinking water, or 38 kWh/m3 of fresh water. Now with this amount of energy available another modern method of sea-water conversion viz. Multiple Ion Exchange Membrane Electrodialysis (M.I.E.M.E., (6) appears to be entirely adequate. The M.I.E.M.E. process, that has matured in recent years, can easily produce drinking water from sea-water at an energy consumption not exceeding the 38 kWh/m3 mentioned above. Admittedly, the water produced will not have the extreme purity of distilled water, but it will be immediately suitable for drinking water (i.e. salt level below 500 p.p.m.) without any further treatment.

Hence with the above combination exactly the same output as required from the Balashi plant can be obtained at exactly the same fuel consumption. The corresponding total investment, however, will be lower than the total cost of the Balashi plant as will be specified hereafter.

The total cost involved in the combined evaporator plant + back-pressure turbine power station together with the condensing turbine power station can be estimated at about $ 7.000.000.- .

The production of 280 t/h of fresh water from sea-water by the M.I.E.M.E. process at an energy consumption of 38 kWh/m3 will involve an average current density of 25 mA/cm2 and an overall current efficiency of 80%. For the capacity required 22.400 m2 of electrodialytic net cell pair area will have to be installed. If a unit price of $ 180.- a square metre of net cell pair area (including all auxiliaries) is assumed the total investment will amount to about $ 4.000.000.- .

This brings the total investment for the schedule described up to . . . . . $ 11.000.000.-

instead of the $ 12.500.000.-

spent on the present plant.

In other words a saving of over 10% on the cost of investment would have been accomplished.

The conditions at Aruba cannot be considered to be representative for the conditions in less developed areas. It is more likely that in general in such areas the need for water meeting the required 500 p.p.m. salt level for domestic purposes will be absolutely predominant as compared to the need for extremely pure boiler feed or chemical process water. If the aim would be to merely provide 500 p.p.m. class water the prospects offered by the application of some recent developments of science and technology would be even more impressive.

This can be illustrated by the following calculation of a hypothetical case of a total fresh (i.e. 500 p.p.m.) water output equivalent to that of the Balashi plant (425 t/h).

Consider a case where the installation of a large power station (of at least 100.000 kilowatts output) is justified (needed). Such a station would be most likely a very high pressure power station in which the so-called re-heat principle would be applied. Furthermore a fairly constant continuous load is assumed. Under such conditions a 40% efficiency can be obtained. Hence in this case 80. 10^6 Kcal of fuel will generate about 37.000 kilowatts of which 3.000 kilowatts are to be spent on the power station itself, leaving a net output of 34.000 kilowatts.

Now - for the sake of comparison - we shall use these 34.000 kilowatts for the supply of 425 t/h of fresh (500 p.p.m.) water and 10.000 marketable kilowatts. This leaves 24.000 kilowatts available for water desalting with the M.I.E.M.E. process or 56 kWh/m3 of fresh water. In this case the load (current density) of the electrodialysers can be increased approximately by a factor $\frac{56}{38}$ which means that the total amount of membrane area (net cell pair area) and consequently the investment will be reduced by the corresponding factor $\frac{38}{56}$, so that the investment for the sea-water conversion plant will amount to about $ 2.700.000.- .

The proportional share in the investment necessary for the power station is estimated at about . . . . . $ 6.300.000.-

for the 34.000 kilowatts mentioned above, so that the total investment works out at . . . . . $ 9.000.000.-

This figure is 28% less than the . . $ 12.500.000.- figure for the corresponding Balashi plant.

Actually the figure of 80.10^6 Kcal of fuel constitutes an arbitrary figure that has been adopted only for the sake of comparison with the Balashi plant.

Upon complete optimalization of the system as a whole, taking into account capital cost as well as running cost for both the power generation and the saline water conversion a lower optimal load (current density, energy consumption) is to be expected.

The description of a detailed optimalization would go beyond the scope of the present paper. It can be easily shown, however, that if the energy consumption mentioned in the first example (i.e. 38 kWh/m3) is maintained also in the present case, the total investment involved in power generation and saline water conversion will stay rather close to the $ 9.000.000.- found before. However, now the total energy consumption will amount to 425 x 38 - 16.150 kW.

Together with the 10.000 kW required, this corresponds with a total fuel consumption of 61.10^6 Kcal/h in the first case. In other words the combination described above might yield not only a 28% saving in investment cost, but also about 25% saving in energy cost.

Consequently, very roughly speaking, a 25% reduction in total cost might be expected.
In this connection "total cost" means the joint cost of power and fresh water. Whether one wishes to make this profit result in a lower water price or in a lower energy price or both is a matter of price policy, not of technology.

Selfevidently all the cost figures used for the high pressure turbine high capacity power stations and saline water converters. They will not hold for small installations though even in that case the qualitative trend will be the same.

In the present paper a specific case has been considered by way of example. A more general treatment of the profits obtainable by appropriate combination of power generation and saline water conversion has been given by one of the authors in an earlier publication (7).

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